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Hydrogen overview and its role in Louisiana decarbonization.

Louisiana Public Service Commission Monthly Business & Executive Meeting. Metairie, LA, November 17, 2022.

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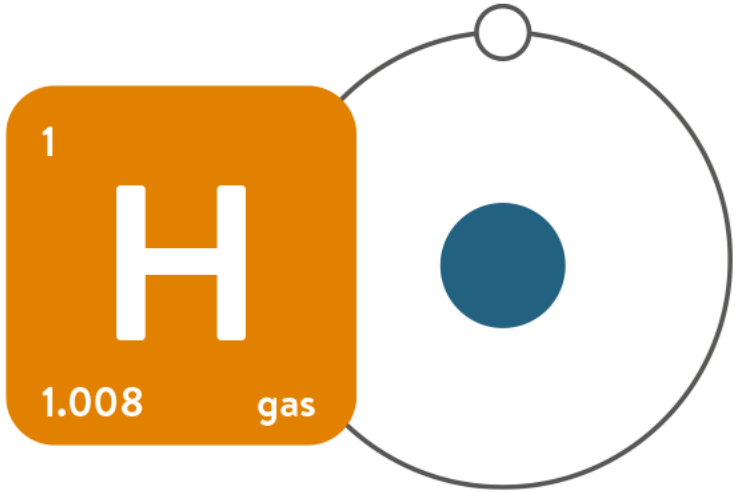
What is hydrogen?

Hydrogen

WHAT IS HYDROGEN?



LIGHTEST AND MOST ABUNDANT

Hydrogen is the first element in the periodic table. It is the lightest, most abundant and one of the oldest chemical elements in the universe.

NEVER ALONE

On Earth, hydrogen is found in more complex molecules, such as water or hydrocarbons. To be used in its pure form, it has to be extracted.

FUEL OF STARS

Hydrogen fuels stars through nuclear fusion reaction. This creates energy and all the other chemicals elements which are found on Earth.

Source: World Energy Council.

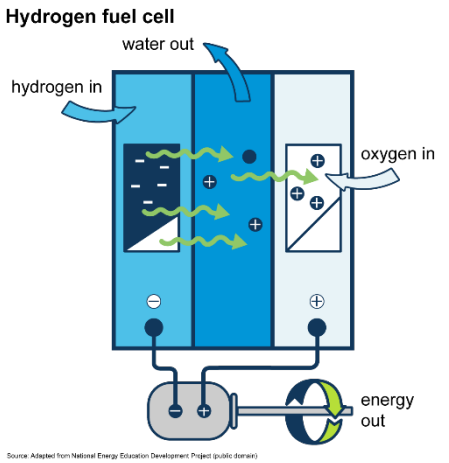
What is hydrogen used for?

Hydrogen is used in many industrial processes

Nearly all of the hydrogen consumed in the United States is used by industry for refining petroleum, treating metals, producing fertilizer, and processing foods. U.S. petroleum refineries use hydrogen to lower the sulfur content of fuels.

Hydrogen is used for exploring outer space

The National Aeronautics and Space Administration ("NASA") began using liquid hydrogen in the 1950s as a rocket fuel, and NASA was one of the first to use hydrogen fuel cells to power the electrical systems on spacecraft.

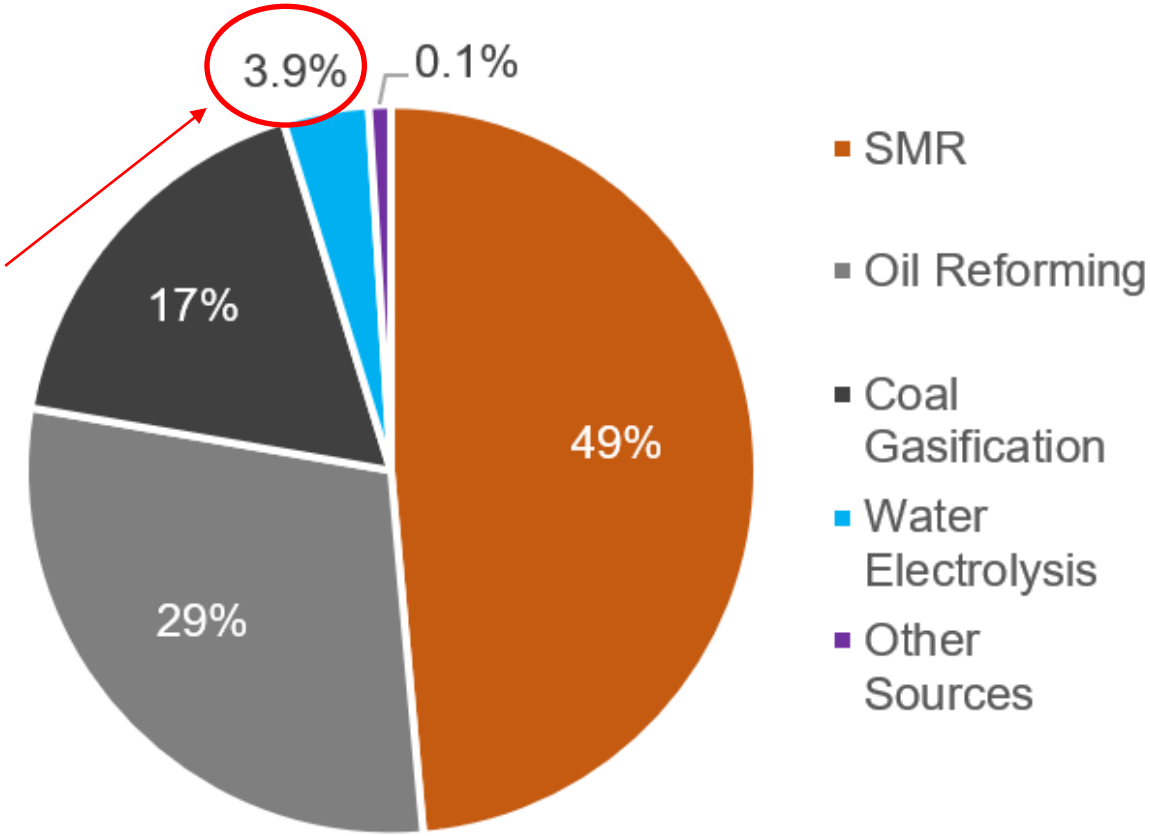


Source: U.S. Energy Information Administration.

How is hydrogen made? global hydrogen production shares

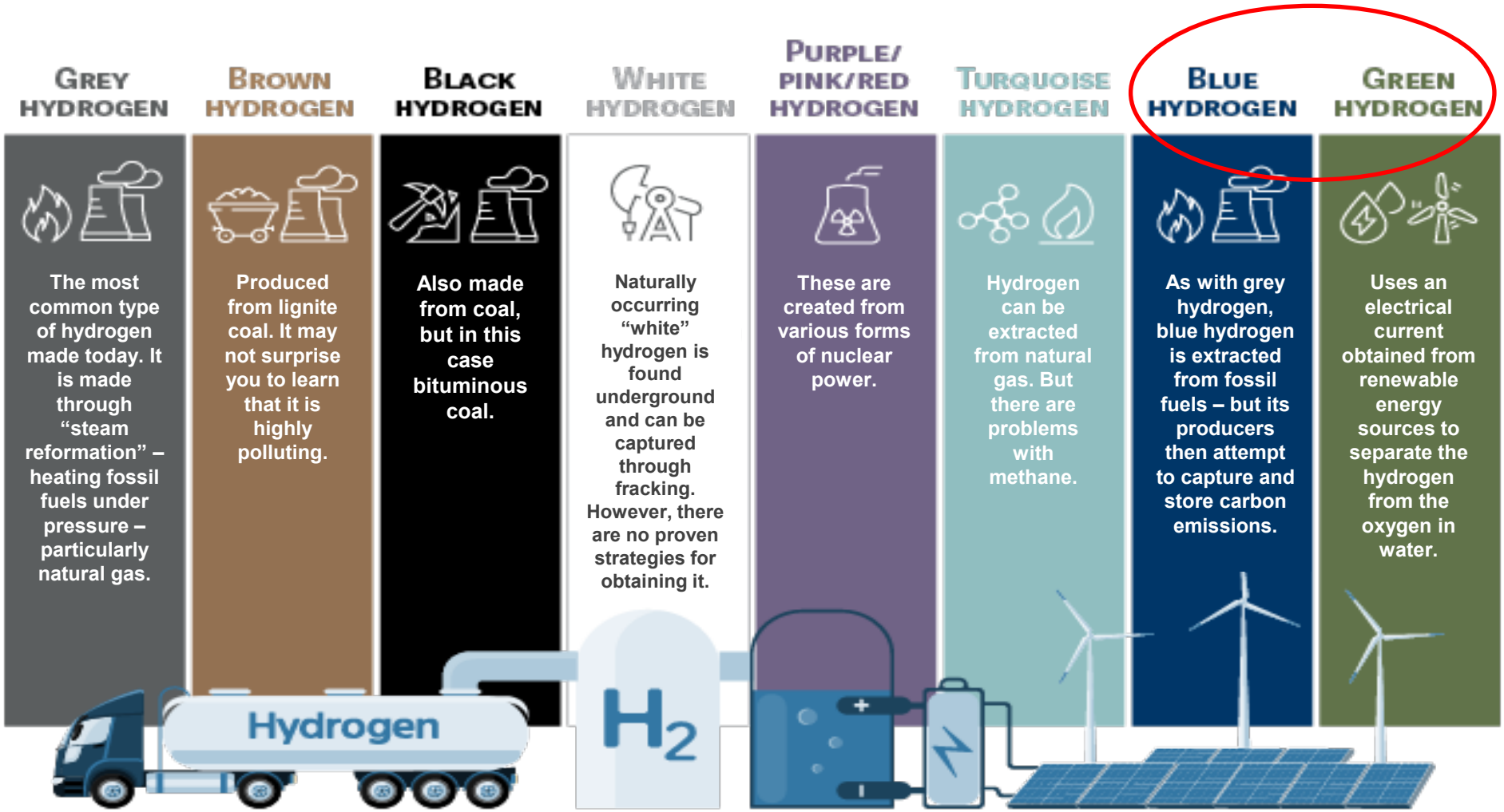
Most hydrogen is produced using **steam methane reformation** or other forms of **hydrocarbon reformation** to break hydrogen from the hydrocarbons.

Note, very little production currently comes from electrolysis.



Source: Dincer & Acar, 2015.

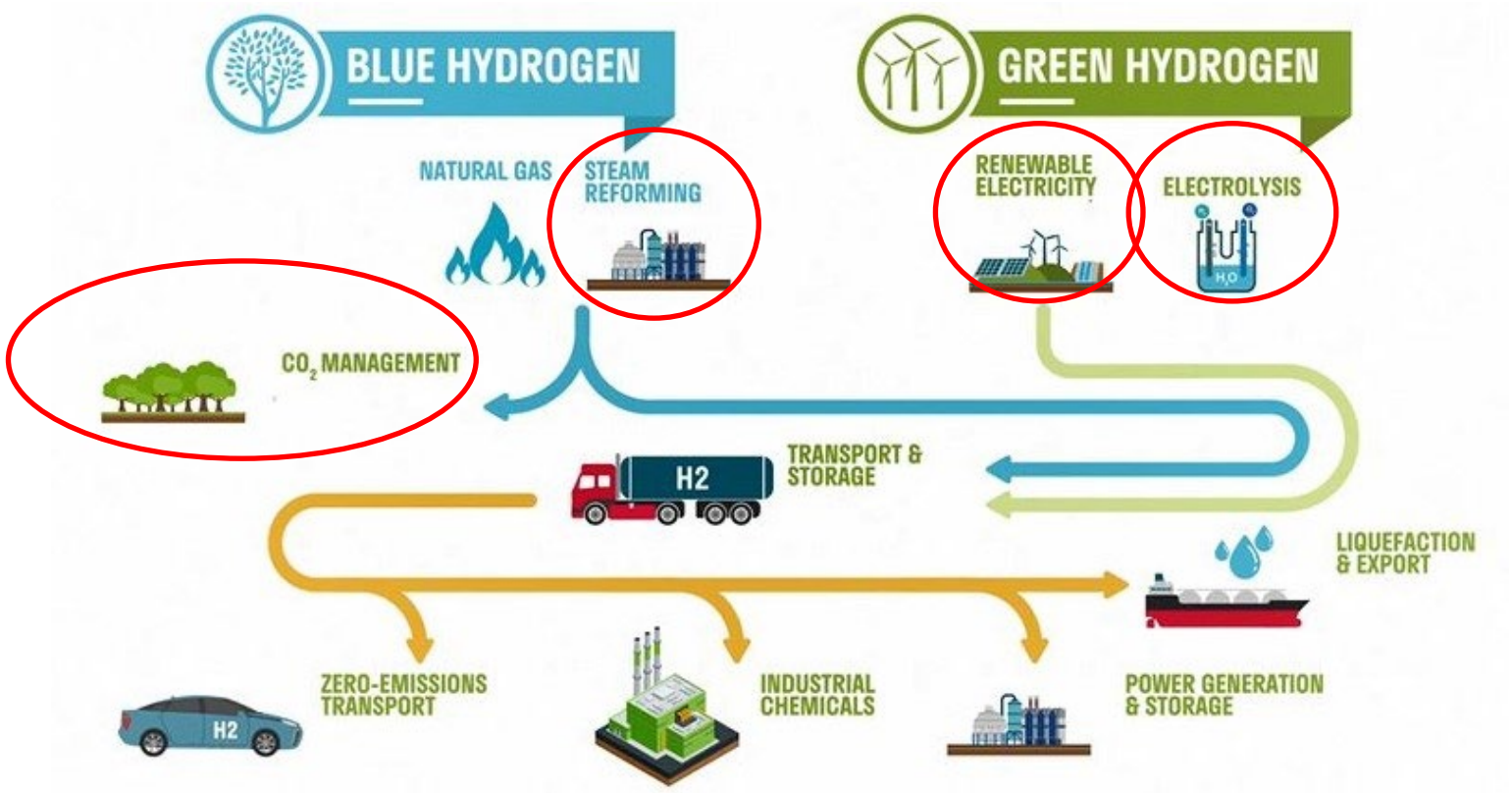
The hydrogen rainbow



Source: Goddin, Neal. Artemis Investments. January 12, 2022

Blue v. green hydrogen

How the hydrogen is made, matters.
Blue uses SMR and CCS;
Green uses RE and electrolysis



Source: Energy Tracker Asia.https://energytracker.asia/hydrogen-oil-green-vs-blue-whats-the-difference

Potential future uses of hydrogen

Residential/Commercial: heating and other appliance uses (cofire with methane by local gas utility).

Industrial: steam (boilers) and heat (furnace) purposes for manufacturing.

Power generation: turbine combustion.

Source: author's construct.

Why Louisiana?

Louisiana importance

Governor-appointed advisory board **unanimously approved the plan** (Feb 1).

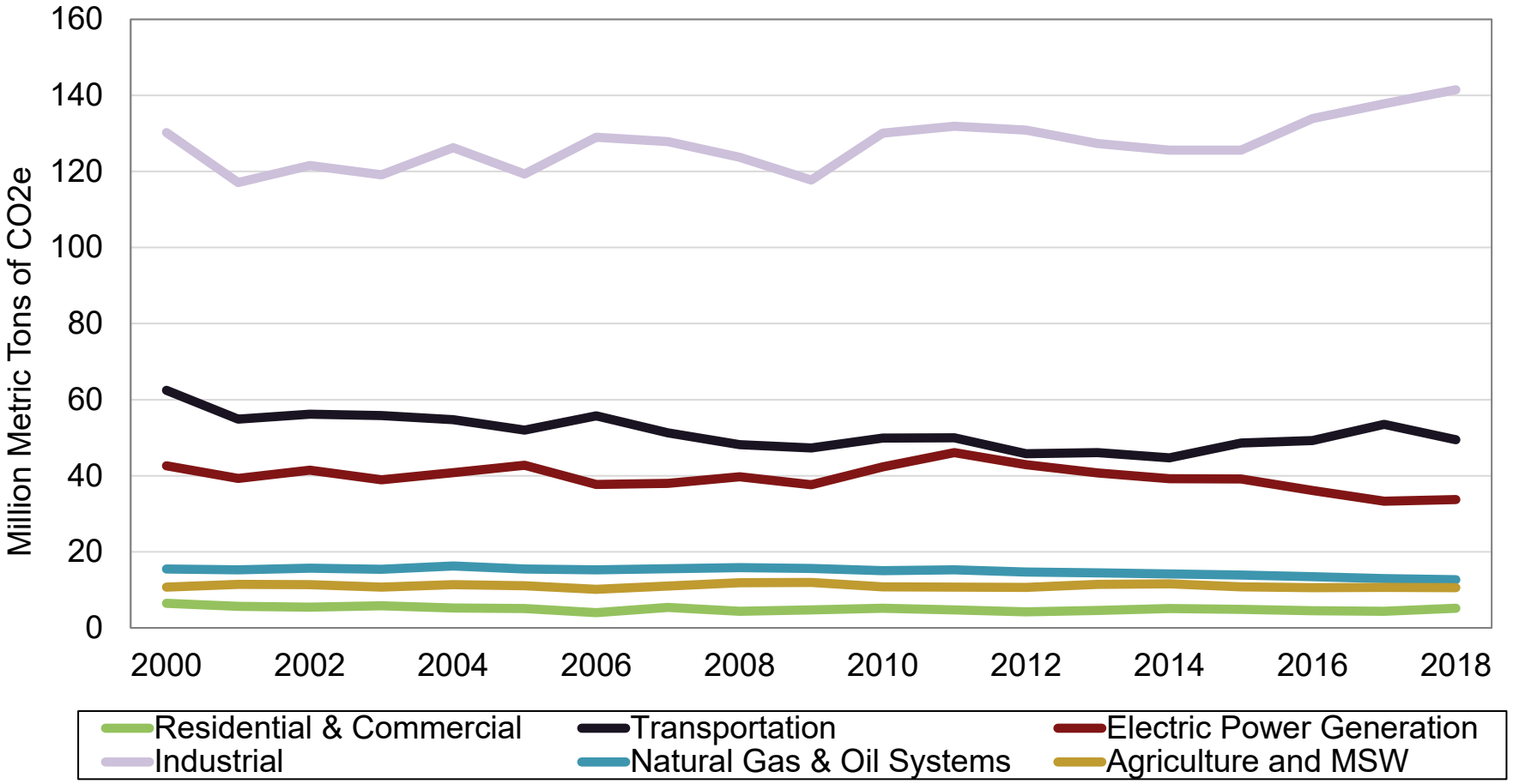
Defines a plan to reduce Louisiana's GHG emission to 26-28% of 2005 levels by 2025; 40-50% of 2005 levels by 2030; and "net zero" by 2050.

Plan calls for **industry to reduce GHG emissions** by using renewables, efficiency, and fuel switching to resources like hydrogen.

Source: Louisiana Climate Action Plan, February 2022.

Louisiana CO_2 emissions per sector

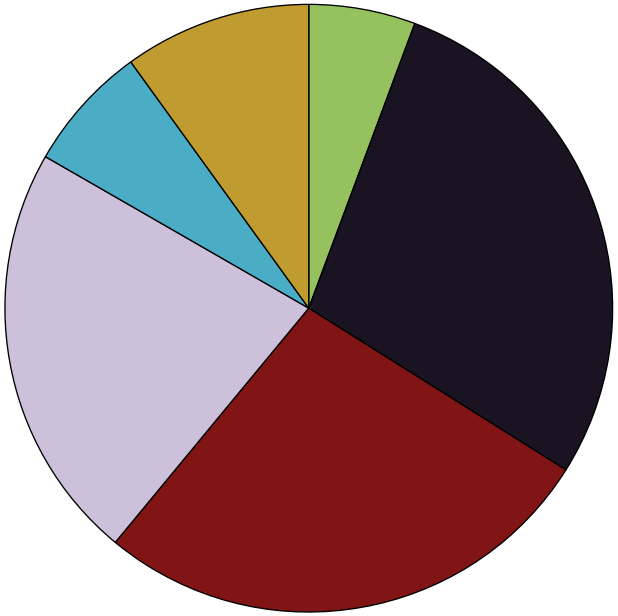
Louisiana GHG emissions are **dominated by the industrial sector**.



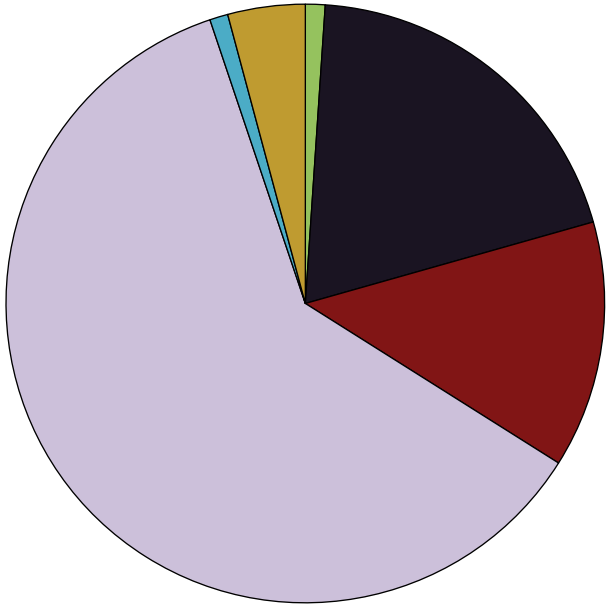
Note: CO_2 emissions are from fossil fuel combustion only.
Source: U.S. Environmental Protection Agency, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018; and State CO_2 Emissions from Fossil Fuel Combustion.

U.S. and Louisiana CO_2 emissions per sector, 2018

In the U.S., **power generation comprises about 35 percent** of overall national emissions.



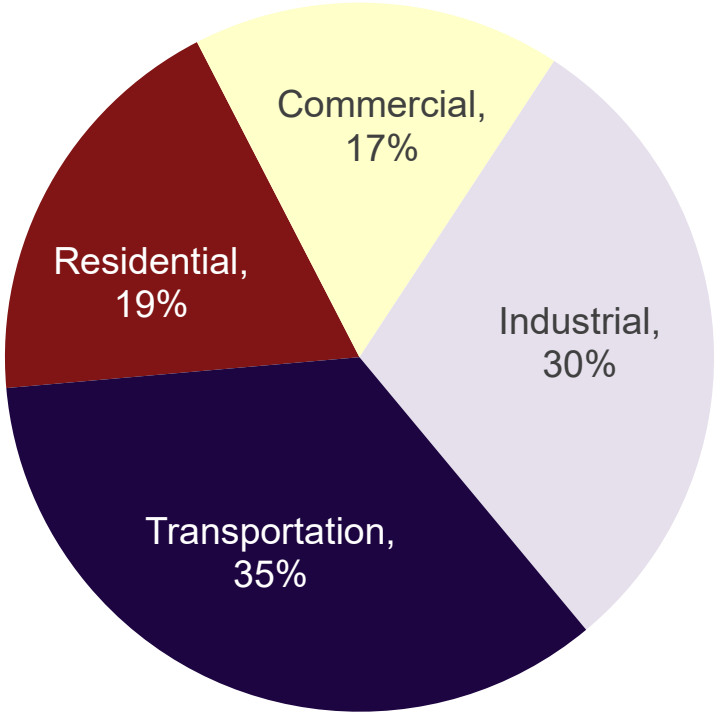
In Louisiana, **power generation comprises about 17 percent of overall state emissions**. Louisiana's primary source of CO_2 emissions comes from **industrial sources**.

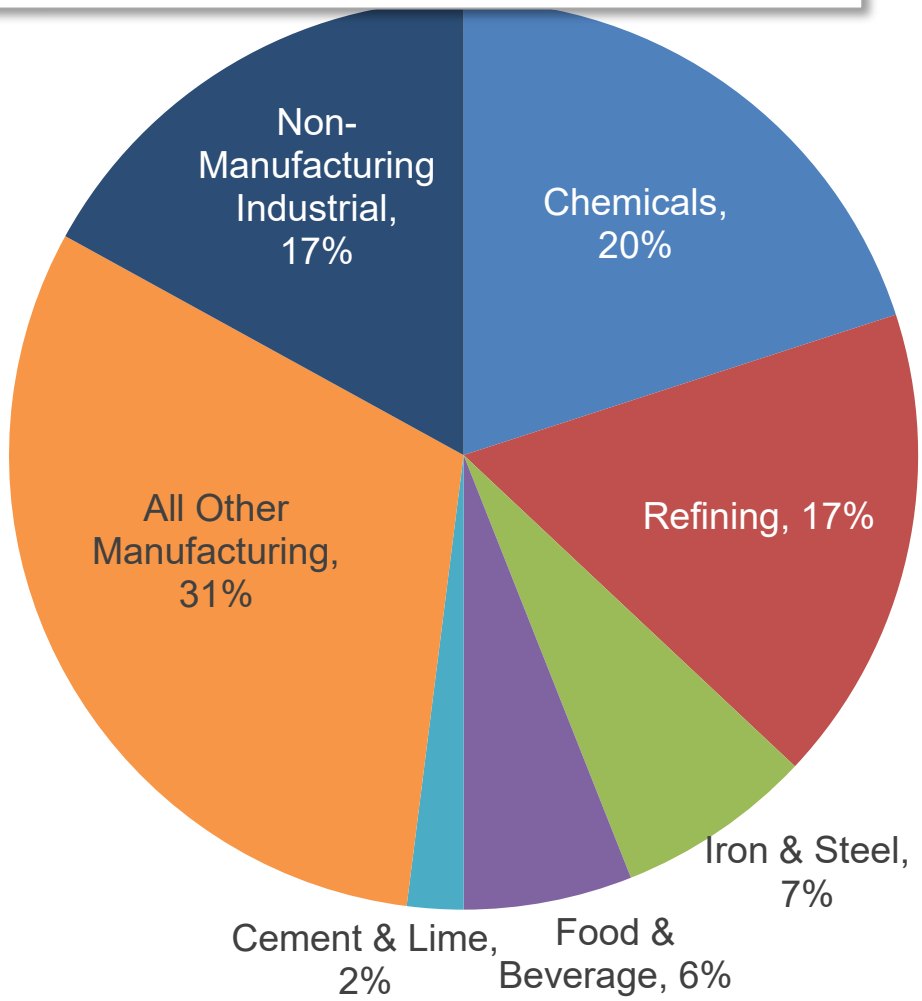


Note: CO2 emissions are from fossil fuel combustion only, adjusted for feedstock use.
Source: U.S. Environmental Protection Agency, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018; and State CO_2 Emissions from Fossil Fuel Combustion.

U.S. industrial energy use & GHG emissions.

Industrial GHG emissions are **concentrated in a six sectors. Refining and chemicals take up 37 percent alone.**



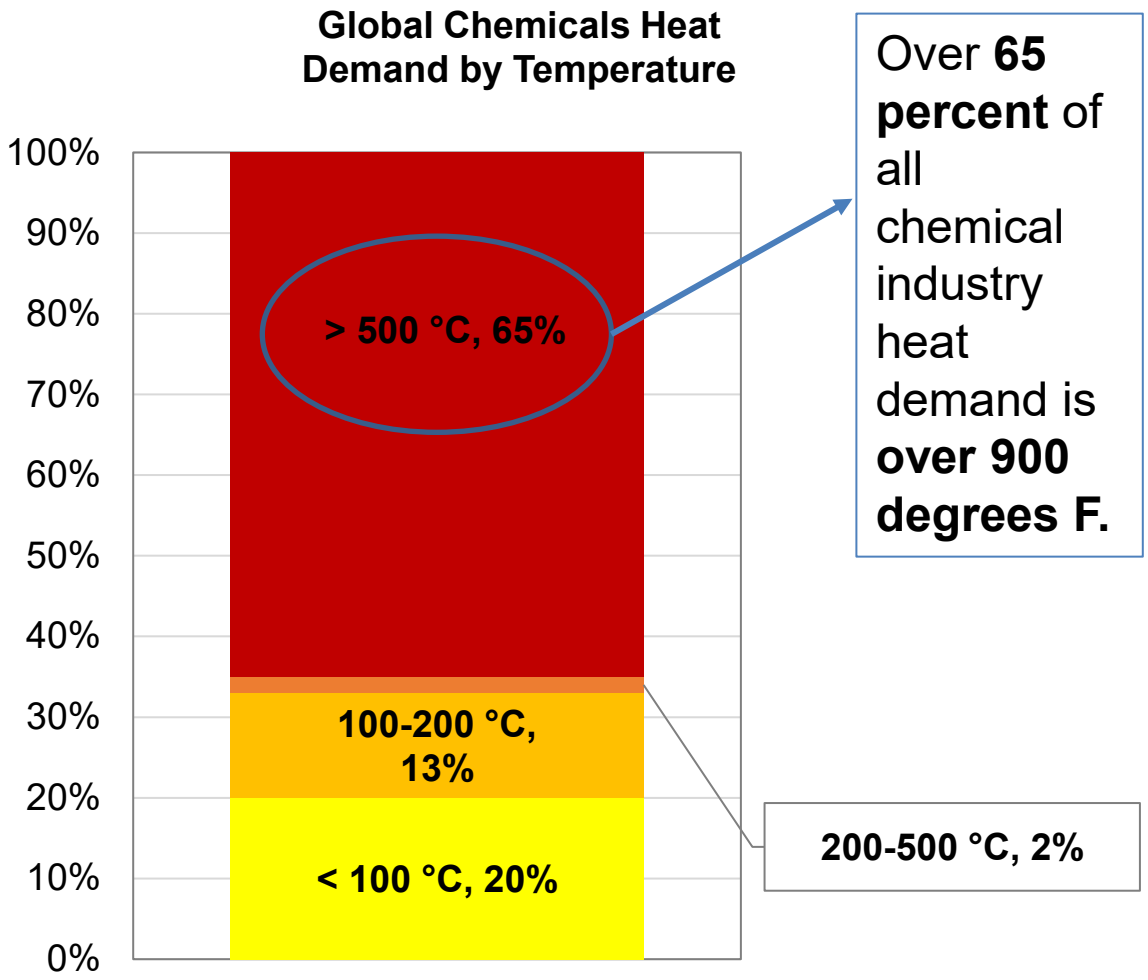


Source: Energy Central; EIA.

Chemical industry use

Over **40 percent** of chemical industry energy use is for **non-feedstock purposes**.

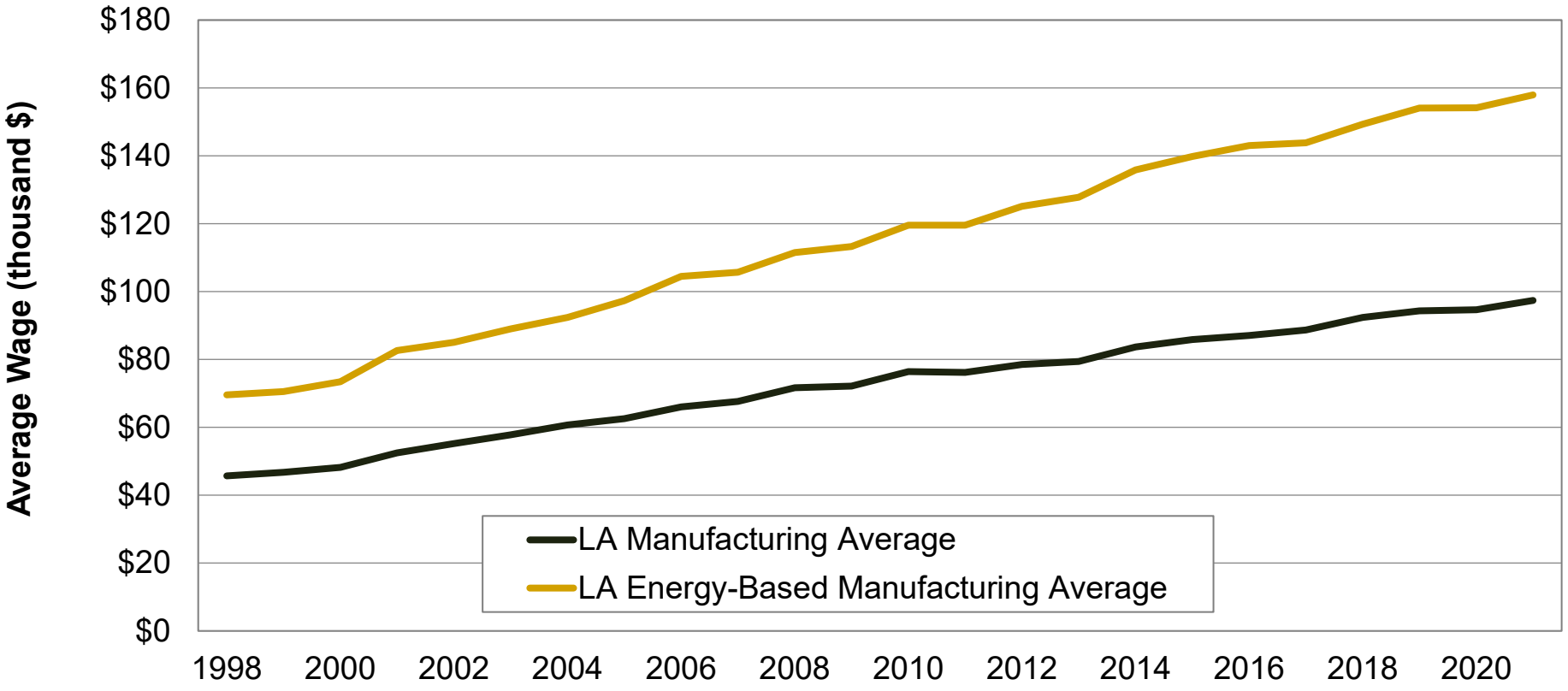
Energy Source	Global Chemical Non-Feedstock Energy Use (%)
Natural Gas	29%
Purchased Electricity	23%
Coal	23%
Petroleum	13%
Purchased Heat / Steam	12%
Bioenergy	>1%



Source: Jeff Rissman. "Decarbonizing Chemicals and other Industries in Louisiana." CTI Presentation. October 8. 2021.

Average wage comparison, Louisiana manufacturing and energy-based manufacturing

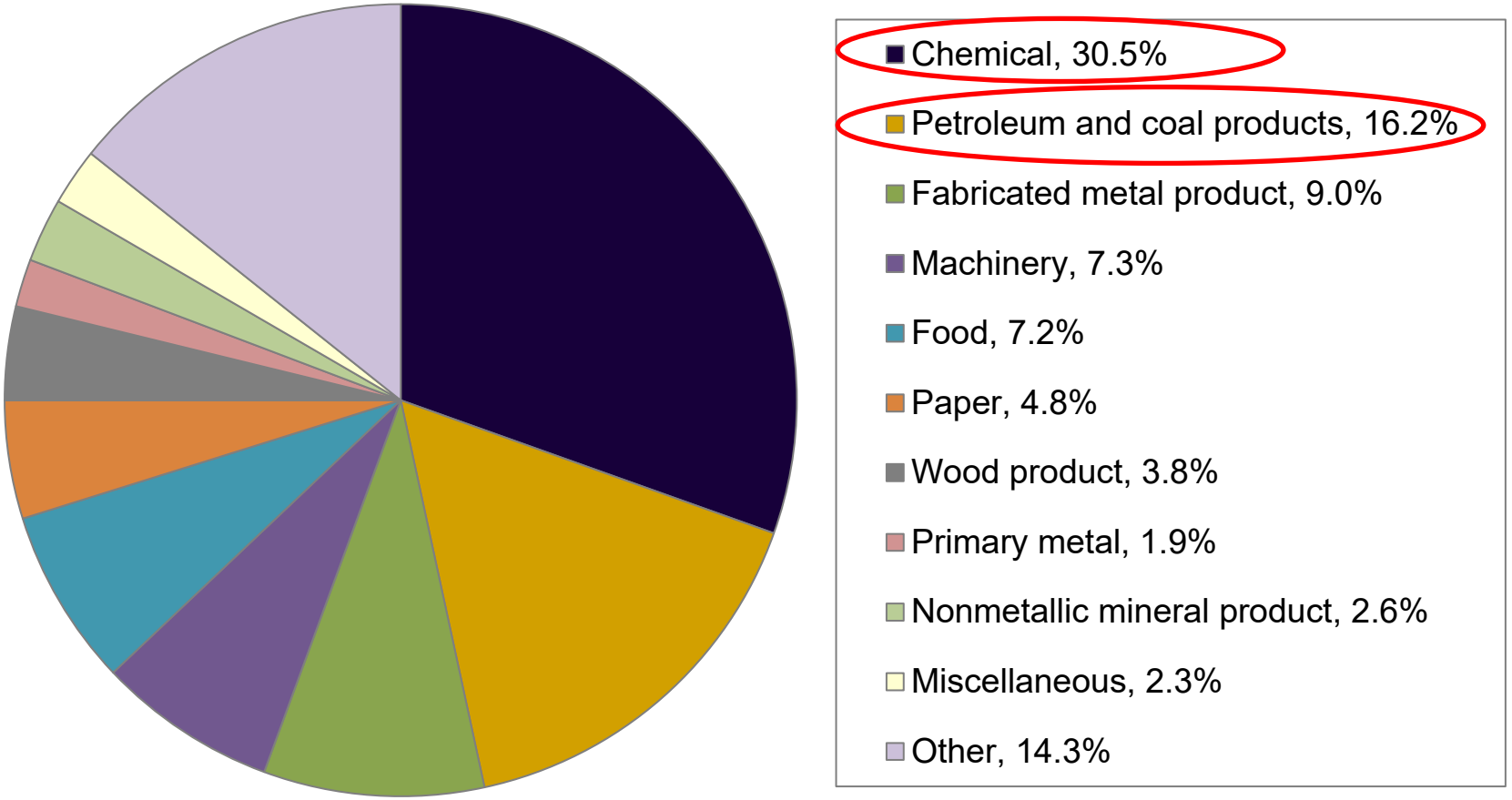
The premium of energy-based manufacturing to total manufacturing is more pervasive in Louisiana. In 2021, **Louisiana energy-based manufacturing wages were 1.62 times traditional manufacturing** and have increased at an average annual rate of 5.5 percent (compared to the manufacturing average of 4.9 percent)



Note: Energy-based manufacturing includes: petroleum and coal products; chemical; and plastics and rubber products manufacturing.
Source: Bureau of Economic Analysis, U.S. Department of Commerce.

Manufacturing wages by sector, Louisiana (2021)

In Louisiana, manufacturing sector wages totaled $13.6 billion in 2021. **Energy manufacturing accounts for 46 percent of total manufacturing wages ($6.7 billion)**.

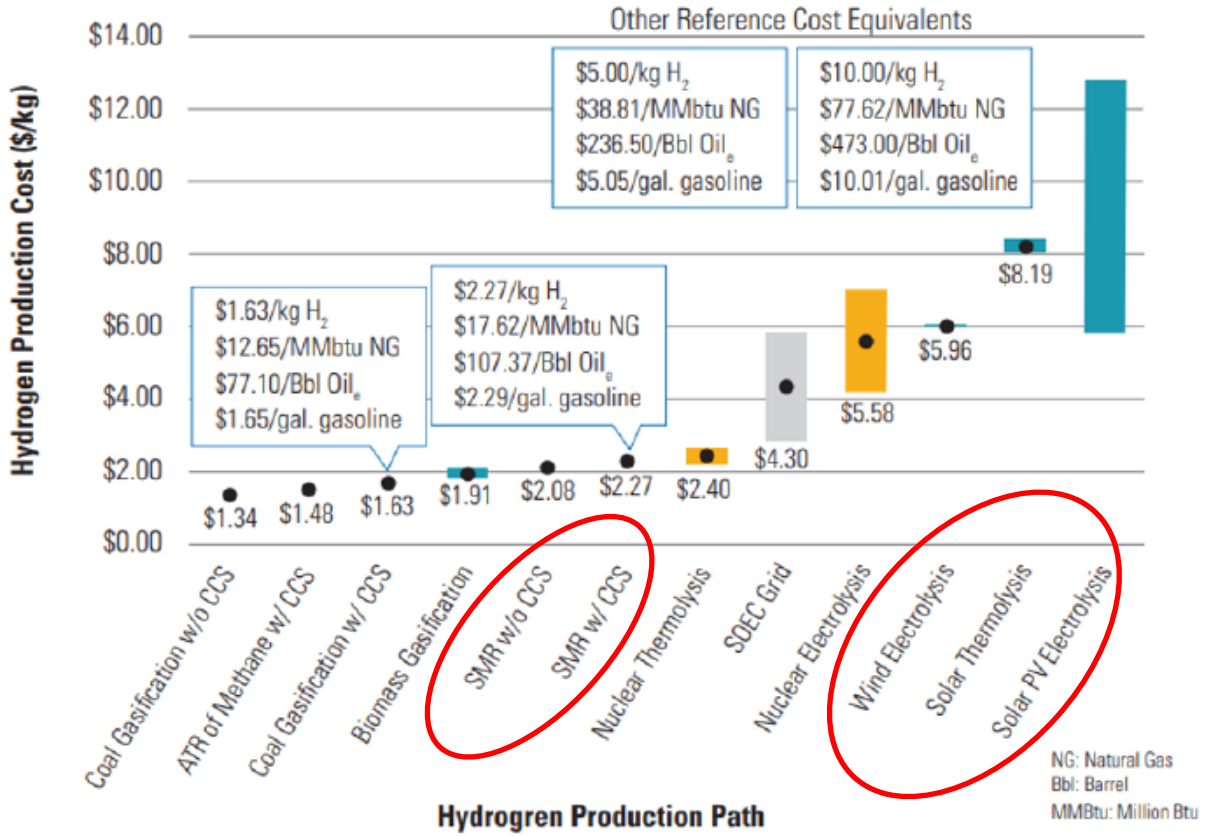


Note: Energy-based manufacturing includes: petroleum and coal products; chemical; and plastics and rubber products manufacturing.
Source: Bureau of Economic Analysis, U.S. Department of Commerce.

Hydrogen challenges & opportunities

Hydrogen cost ranges

Natural gas-based production methods with CCUS are the more likely cost-effective transition methods.



USDOE, 2020. Hydrogen Strategy, Enabling a Low-Carbon Economy: https://www.energy.gov/sites/prod/files/2020/07/f76/USDOE_FE_Hydrogen_Strategy_July2020.pdf

Source: Frank Frey, GHD; "Hydrogen and CCUS"

Salt cavern storage constraints

US Hydrogen Storage	Hydrogen Blend 5%	10%	20%	50%
Energy Equivalent Consumption (BCF)[1,2]	31,533	32,659	35,172	45,723
Volume Hydrogen Req'd (BCF)	1,577	3,266	7,034	22,862
Hydrogen Working Gas Capacity (BCF)[3]	249	517	1,113	3,617
Approximate Salt Cavern Facilities[4]	19	40	85	277
Salt Caverns[5]	62	129	278	904

NOTES
1. Consumption based on 2020 natural gas consuption of 30,482 BCF per EIA
2. Energy Equivalency assumes H2 energy density is 33% of natural gas
3. Hydrogen Storage Capacity based on ratio of total storage to total consumption for natural gas per EIA (2019)
4. Cavern Facilities based on average work gas per Salt Cavern facility per EIA
5. Salt Caverns assumes average 4 BCF working gas per cavern

Existing Natural Gas Storage Facilities (US, 2019)				
Storage Type	Facilities	Working Gas (BCF)	Avg Working Gas (BCF)	% of Annual Consumption
Aquifer	47	403.81	8.59	1%
Depleted Field	328	3,935.13	12.00	13%
Salt Dome	37	483.17	13.06	2%
TOTAL	412	4,822.11	11.70	16%

Source: Frank Frey, GHD; "Hydrogen and CCUS"

Louisiana's hydrogen economy

Louisiana already has a **substantial hydrogen economy with a large number of buyers, sellers, and infrastructure (direct and supporting).**

Buyers

Sellers

Marketers

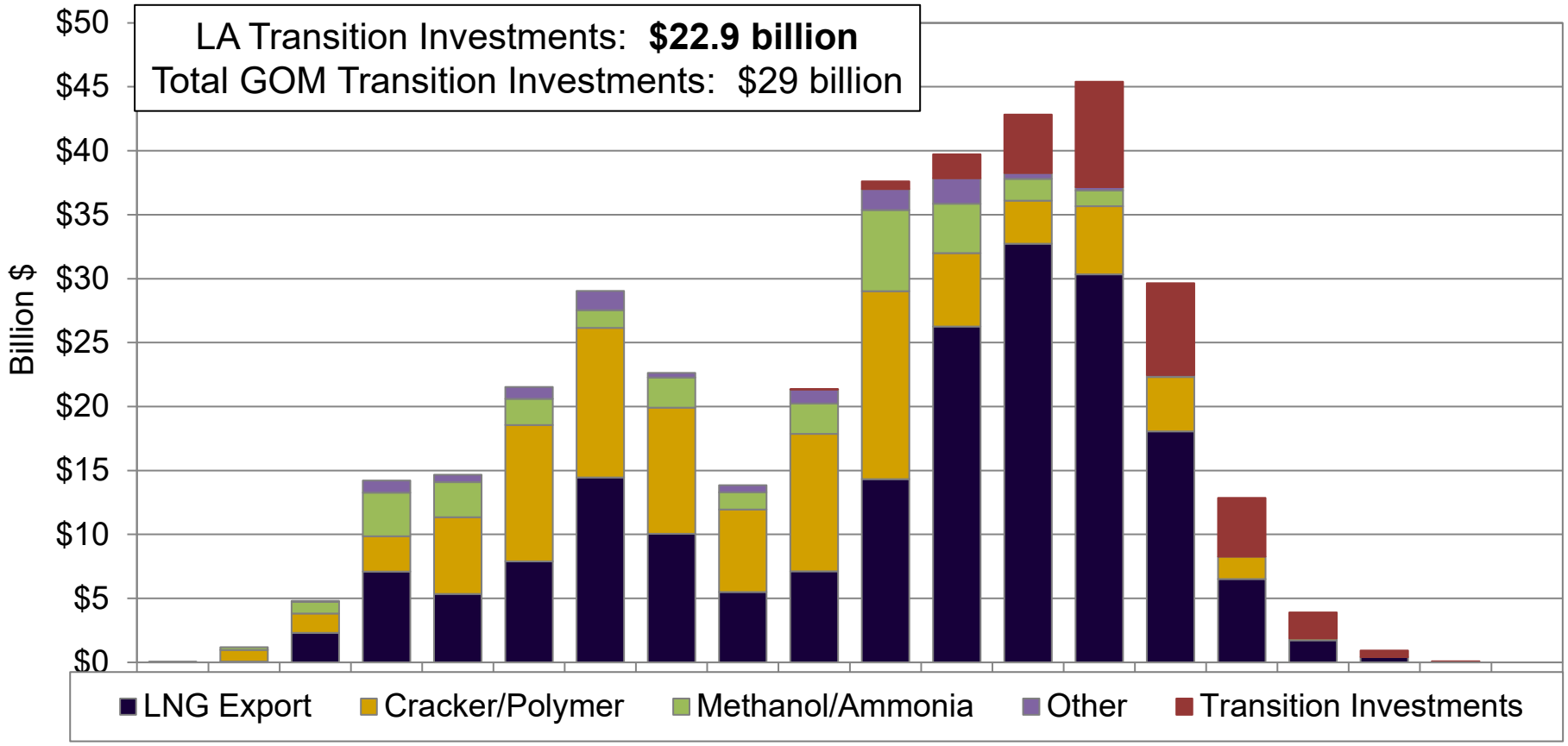
Other Institutions

Supporting infrastructure (H2 and CCUS; pipe & storage)

Source: https://esgreview.net/2021/11/03/louisiana-selected-for-hydrogen-megaproject/.

GOM energy manufacturing investments by sector.

Large number of future investments tied to energy transition. Note the Inflation Reduction Act ("IRA") has **$3.2 billion in additional CCS tax credits** and **$7.8 billion in clean hydrogen**.



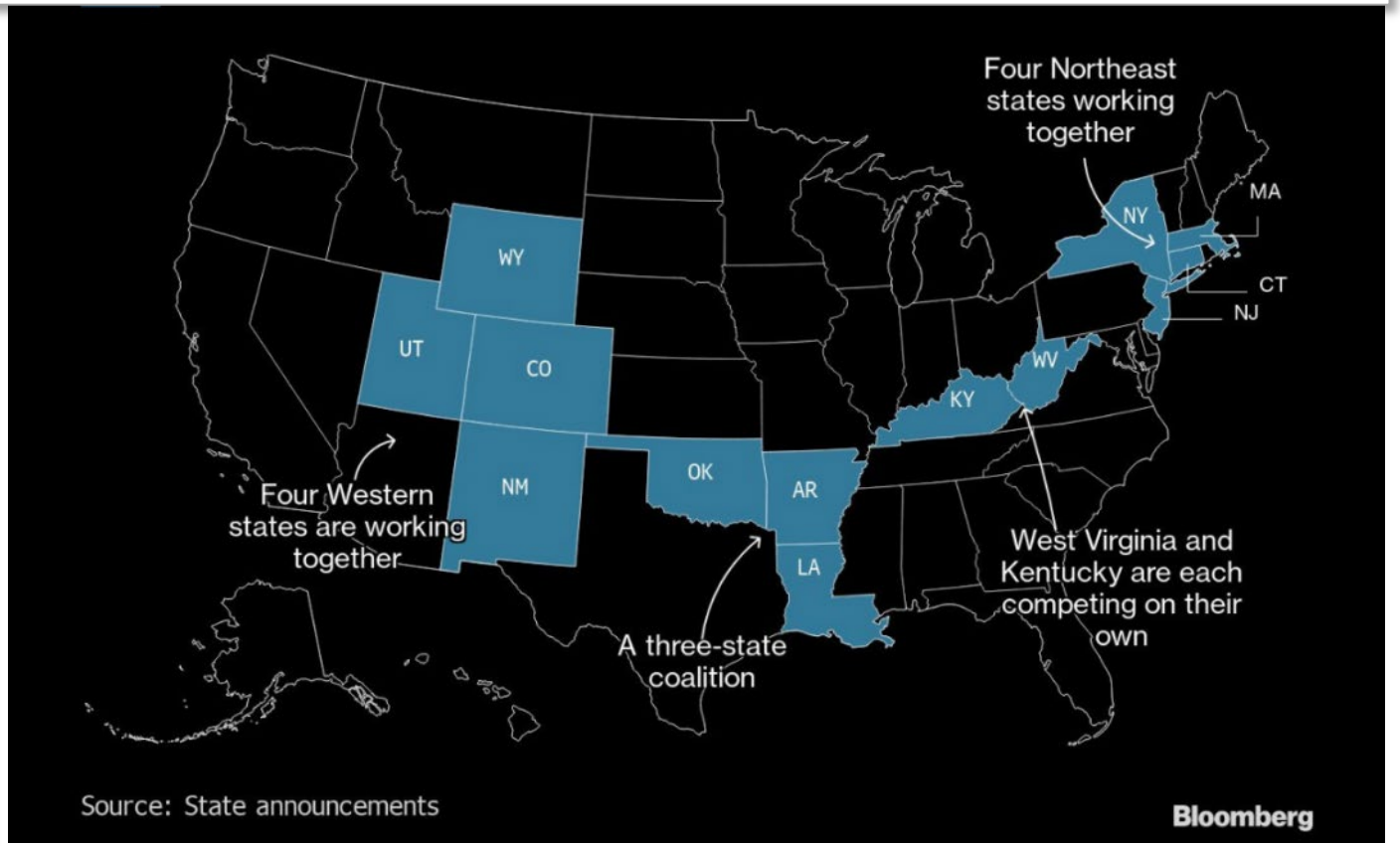
Source: Authors Construct; capex for announced projects with missing information were estimated using available data from average/typical facility type/cost.

Hydrogen hub funding support

As much as **$8 billion in funding** (Infrastructure Investment and Jobs Act or "IIJA") to support hydrogen hubs. **Louisiana is part of three-state coalition (project "HALO")**.

Project HALO

- Concept paper submitted on Nov 5, 2022.
- DOE is currently reviewing concept paper.
- Subset of proposals will be selected by DOE by Dec. 2022
- Ongoing work on full proposal due April 7, 2023.



Source: https://www.supplychainbrain.com/articles/34882-bidens-hydrogen-hub-plan-sparks-8-billion-race-among-us-states

Conclusions

Conclusions

- **Industrial carbon emissions are high** in energy producing states, particularly those along the Gulf Coast.
- These industries, however, are **important components of many regional economies**. Their loss could be devastating.
- **Hydrogen will be a very important decarbonization tool** over the next several years in order to meet many state's clean energy and climate goals.
- Hydrogen is expensive and will also **require additional storage and transportation build out.**
- **CCUS is a critical component of most decarbonization tools, including hydrogen.** Difficult if not impossible to produce the hydrogen volumes needed to meet industrial needs with electrolysis alone.

Questions, comments and discussion.

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